yet the tube is not only inverted in position, but the stream lines occupy only the central portions, and the lines of ψ become tangent to the plane whose height is H_0 at certain distances from the center. The fundamental equations for the tornado are 303–308. $\psi = +\frac{c}{2} \varpi^2 z$ holds for the tornado with vertical axis positive downward, and the single bounding plane at the distance H_0 above the ground. $\psi = -\frac{c}{2} \varpi^2 z$ is the equation for the cyclone with the vertical axis positive upward. A multitude of minor relations and comparisons can be drawn from the two sets of equations 303–308 and 488–490. If the lower part of fig. 20 be looked at as if the horizontal axis were the vertical, we have a picture of the tornado tube. The diagram is not good because not drawn to scale, but the idea is easily understood. Hence, one law serves for all types of local storms, cyclones, hurricanes, and tornadoes, which thus theoretically differ from each other only in their dimensions and in the details by which they are formed. Cyclones are generated chiefly by horizontal convection currents; hurricanes have a stronger vertical convection current and also horizontal convection currents; tornadoes arise chiefly from vertical convection, assisted by some horizontal currents which counter flow in the cumulus level.

It may be remarked that the stream lines indicated by Ferrel, page 300, Recent Advances, are conjectural only, and do not conform to the theory of stream lines in a vertical vortex tube, nor to observation, which shows that the air is quiet close up to the boundary of the tornado tube.

THE WATERSPOUT OFF COTTAGE CITY, MASS., AUGUST 19, 1896.

The result of the computation on this interesting waterspout is added, and it shows the dimensions and velocities in metric and English measures which were derived from the observed distances and the formulæ. The most important feature is the value of the vertical velocity of 35 miles per hour at the sea level. See Table 20.

ANNALS OF THE ASTROPHYSICAL OBSERVATORY OF THE SMITHSONIAN INSTITUTION, VOLUME I.[1]

By S. P. LANGLEY, Smithsonian Institution, dated April 29, 1902.

The work upon the infra-red solar spectrum, described in this volume, is the latest outcome of investigations with the bolometer, begun with the invention of that instrument by the writer about the year 1880. In the use of the bolometer (in principle so well known now as to need no description) the practise at Allegheny during the nearly ten years that studies of the infra-red spectrum of the sun were in progress there, required at least two and preferably three observers. One made and read the settings of the spectroscope, a second read as often as he could the indications of the galvanometer, while the third recorded all the observations and operated the shutter in front of the slit of the spectroscope. In those days the galvanometer, though far less sensitive than that now employed, was rarely free from "drift," or wandering of the spot of light upon the scale and this "drift" was usually so rapid that the spot of light would cross the whole scale within a few minutes.

It had been my intention at Allegheny to replace the tedious and incomplete system of eye observations at the galvanometer by an automatic photographic recording apparatus, but the "drift" stood as a seemingly insuperable obstacle in the way. The difficulty was attacked immediately after the installation of apparatus at the Astrophysical Observatory at Washington in 1891. Without stopping to mention details, it need only be said that by persistent efforts carried on through more than ten years as described in the early chapters of the Annals, and with the aid of several devices which the reader may find there illustrated, these obstacles have been removed and it has become possible to use the galvanometer with perfect success to produce a purely automatic record, in connection with the bolometer, and with a photographic recording apparatus.[2]

As thus perfected, the procedure of mapping a portion of the spectrum is this:

A prismatic spectrum is formed by a spectroscope of the so-called "fixed arm type," in which, as the reader will recall, the ray which is in minimum deviation is given a certain fixed direction by an optical method, so that the observing instrument remains fixed also. This observing instrument is here the bolometer, whose essential part is a Wheatstone's bridge, chiefly formed of two excessively narrow and thin strips of platinum, only one of which is exposed to the radiation to be studied. On looking into the eyepiece of the bolometer, this appears like a single spider web wire of a micrometer, seen against the background of the spectrum, for instance just below the A line, whose position might be read by it on the large azimuth circle on which the bolometer is mounted. But this thread is not alone a fiducial index, for since it conveys an electric current it is also sensitive and comparable to a nerve which will recognize the heat or cold which falls on it, and not only recognize but accurately measure it by the changes set up in the current in question.

The whole forms an electrical thermometer which actually measures to very much less than the millionth of a degree.

As the bolometer strip is warmed or cooled the galvanometer mirror turns to and fro, and the spot of light which it reflects passes to and fro on its scale, which is here a photographic plate. A clockwork of extreme accuracy moves the rock salt prism so that the spectrum marches uniformly across the bolometer thread at a rate, let us say, of one minute of arc in one minute of time, while the photographic plate moves as regularly in a vertical direction at right angles to the movements of the galvanometer spot at a rate, for example, of a centimeter in one minute of time. There is thus produced a curve called a bolograph, in which ordinates accurately correspond to relative amounts of energy, and abscissae to deviations in the prismatic spectrum. Depressions in this curve correspond to cooler lines or bands in the spectrum; the visible Fraunhofer lines, which are cool to the bolometer, appear as such deflections in the bolographs; the invisible lines, which are wholly insensible to the eye and chiefly insensible to the photographic plate, but which are recognized everywhere by the bolometer and discovered to fill the whole infra-red, are recorded also.

The first object of the principal research described in the Annals was to map out in detail the hitherto scarcely explored region of the solar spectrum between the limit of the visible, just below A at about 0.8μ and a wave length of 5.3μ, beyond which little energy reaches the earth from the sun. In the accompanying illustration, Plate I (similar to Plate XX of the Annals), two bolographs taken on different days are superposed to show the coincidence of their indications, which directly represent the solar energy in this (invisible) part of the spectrum, and beneath is a corresponding line spectrum drawn to show the region mapped in a more conventional aspect. At the left we see the comparative space occupied by the Newtonian or visible spectrum, on the scale of the average dispersion of the prism in the infra-red. Above is a curve obtained by Lamansky about thirty years ago, which gives the sum of the knowledge of the infra-red spectrum at that time, and was then justly regarded as a great triumph.

In the work of the Astrophysical Observatory over 700 lines

[1] Washington, D. C., Government Printing Office, 1900.

[2] The "drift," long the great enemy to bolometric research, has become so much reduced that often it amounts to less than a single centimeter an hour, whereas in the old days a centimeter a minute would have been regarded as relative perfection.

have been found between the *A* line at 0.76μ and a wave length of 5.3μ. Their determination required over 40,000 measures with the comparator, a careful comparison of upward of twenty bolographs, and a long subsidiary research on the dispersion of rock salt, all of which the reader may find in the Annals.

To the meteorologist, who, perhaps has little concern with the small solar absorption bands discovered, the work has nevertheless several features of distinctive interest. It will be remembered that beyond the vicinity of 1μ, where occur the bands ρ, σ, τ near the Ultima Thule of the spectrum, as defined by the elder Draper, nearly every line has been discovered by the bolometer down to and including the great band Ω. Beyond this lies a region first discovered by the writer on Mount Whitney in 1883, called the New Spectrum in Plate I, in which every inflection and line, without exception, was discovered with the bolometer. There are in the infra-red spectrum, above a wave length of 4μ, five great bands of progressively increasing magnitude, which are all known to be due to water vapor.[3] They lie, respectively, at 0.92μ, 1.1μ, 1.4μ, 1.8μ, and 2.6μ. The first of these is in the neighborhood of the bands which the elder Draper discovered upon a phosphorescent screen and called α, β, γ. The present designation of this water vapor band at 0.92μ was, I believe, given by Abney. The next four bands have been distinguished by me as Φ, Ψ, Ω, and X, the two latter being first observed at Allegheny; Ω having been, till the Mount Whitney expedition, supposed to be the limit of the solar spectrum. I have said in my writings, in substance, that all these are probably due to water vapor, but the demonstration that they are so has been given since by others.

In the region below Ω, at the particular points which I have called x_1 and x_2, the energy curve assumes the form of a high elevation near noon, but toward the afternoon melts away so that what was a summit becomes a valley. This is probably due to the absorption of water vapor with a mingling of carbon dioxide. A little lower, the great band Y (first observed by me at Allegheny) has been found by others to be caused by the absorption of carbon dioxide, but I will not enlarge upon the nature of these bands further.

These six regions of powerful absorption of the sun's rays by the gases of the earth's atmosphere, extend in the aggregate over a range of wave lengths three times as great as the visible spectrum, and there are still in addition extensive regions of considerable, though less complete, absorption by water vapor.

It is found that great changes occur in the amount of terrestrial absorption by water vapor in the region studied. The full extent of these changes was not recognized at the time the Annals appeared, but in Chapter VII much of interest in this connection is given. A yearly cycle of variations is described and illustrated in the Annals and is confirmed by subsequent bolographs. Later and, as yet, unpublished work, especially within the present calendar year, has added most materially to the knowledge of these changes of terrestrial absorption.

It appears that during the spring months water vapor absorption is at a minimum in Washington. In summer the absorption greatly increases, reaching its maximum in August. The air again becomes dryer apparently for a time in the autumn, after which another period of greater absorption succeeds.

My attention has lately been called to the consonance of this cycle with the results of actinometry carried on since 1883 at Montpellier, in France. The reader's attention is drawn to a plot of these results which appeared in the MONTHLY WEATHER REVIEW for April of the present year. The Montpellier observers are able to note by the aid of the Crova recording actinometer a yearly cycle of fluctuations in the amount of solar radiations received at the earth's surface. I have myself used the excellent Crova actinometer with good results in the determination of solar radiation. At the same time, the bolographic work I have referred to shows that the fluctuations that the French observers have noted are caused in all probability by a varying absorption of the earth's atmosphere attending changes in the amount of water vapor which it contains. Recent bolographic observations (made here in March, 1902), have shown that fluctuations in the amount of solar radiation received at the earth's surface amounting to as much as 7 per cent of the whole, may be occasioned merely by a difference in water vapor absorption between two days in the same week that appear to the eye to be equally clear. Far in excess of this is the change due to the same cause between spring and summer.

From these examples it will be apparent how great are the possibilities of usefulness for the recording spectrobolometer in connection with the study of atmospheric absorption, now that the bolometer has reached the present stage of perfection.[4] A bolograph of the solar spectrum from the violet down to a wave length of 2.5μ is now taken in a quarter of an hour more perfectly by far than could be obtained in two entire years' work at Allegheny, showing the principal absorption lines both in the visible and infra-red spectrum, with sufficient accuracy and detail for purposes of study. The apparatus with certain accessories for standardizing purposes can be used for actinometry, either of the total solar radiation or, what is more valuable, for minute portions of the spectrum. Such researches can not but add, it would seem, to the knowledge of the physics of the atmosphere of the earth, and may even extend to what is possibly of equal importance to us, the study of the atmosphere of the sun.

I have elsewhere ventured the hope that such steps as these may lead to advances in the way of long range forecasting of the weather.

My hopes have, possibly, been regarded as unduly optimistic by many who may have understood me to anticipate a something of speedy attainment. I fully recognize how dimly we can grasp the problem with our present knowledge, but I think I see, in researches which teach us more of the effects and changes of our atmosphere as a whole and in part, and of the sun's atmosphere as a whole and in part, something which will make the problem before us—one which concerns all life in this world—real and definite, and finally largely, if not wholly, solvable.

I can not conclude this brief article without saying that in the beginning this work was strictly mine, the bolometers which were originally used in it having been made throughout with my own hands, but now, owing to other cares and interruptions from administrative duties there is hardly

[3] Mr. Very, in a recent number of this REVIEW, correctly points out that the two first mentioned of these bands are due to water vapor, though this is not so stated in the first edition of the Annals. This error is corrected in a later edition prepared as a Senate document.

[4] I have elsewhere remarked (Philosophical Magazine, July, 1901), that the accuracy as well as delicacy of the bolometer may be considered (1) in regard to its sensitiveness to small amounts of heat; (2) to the accuracy of measurement of those small amounts; and (3) to the accuracy of its measurements of position. As to the first, while it was considered to be remarkable twenty years ago that a change of temperature of one ten-thousandth of a degree could be registered, it is believed now that with the last improvements which Mr. Abbot of the observatory of this institution has lately introduced into the galvanometer, less than one one-hundred-millionth of a degree in the change of temperature of the strip can ordinarily be registered; that as to the second relationship, while careful photometric measures imply a probable error of 1 per cent, the error with the bolometer is insensible and is at any rate less than one-fiftieth of this amount; and that as to the accuracy of its measures of position, in place of an error of a considerable fraction of a degree, as in Lamansky's work, the probable error in feeling the relative position of one of these invisible lines is less than one second of arc, a statement which might hardly appear credible but which is correct.

any part of the experiments, or of the volume which describes them, in which I have not been helped by Mr. C. G. Abbot of this observatory, whose aid I have had pleasure in elsewhere acknowledging.

HAWAIIAN CLIMATOLOGICAL DATA.

By CURTIS J. LYONS, Territorial Meteorologist.

GENERAL SUMMARY FOR MAY, 1902.

Honolulu.—The level of water in artesian wells fell during the month from 34.10 to 33.05 feet above mean sea level. May 31, 1901, it stood at 33.20. The average daily mean sea level for the month was 9.76 feet, 10.00 representing the assumed annual mean. Trade wind days, 31 (5 of north-northeast); normal, 24; average force of wind (during daylight), Beaufort scale, 3.2; cloudiness, tenths of sky, 4.7; normal, tenths of sky, 4.4.

Rainfall data for May, 1902.

Stations.	Elevation.	Amount.	Stations.	Elevation.	Amount.
HAWAII.			OAHU—*Continued.*	*Feet.*	*Inches.*
HILO, e. and ne.	*Feet.*	*Inches.*	Makiki Reservoir	120	1.35
Waiakea	50	13.35	U. S. Naval Station, sw	6	0.24
Kaumana	1,250	21.74	Kapiolani Park, sw	10	0.00
Pepeekeo	100	12.55	Manoa (Woodlawn Dairy), c.	285	7.63
Hakalau	200	18.63	Manoa (Rhodes)	300	11.33
Honohina	300	19.02	School street (Bishop), sw	50	1.05
Laupahoehoe	500	29.99	Insane Asylum, sw	30	1.09
HAMAKUA, ne.			Kalihi-Uka, sw	260	7.02
Kukaiau	250	17.51	Nuuanu (W. W. Hall), sw	50	0.95
Paauhau (Mill)	300	11.90	Nuuanu (Wyllie street), sw.	250	2.50
Kukuihaele	700	16.24	Nuuanu (Luakaha), c	850	12.14
KOHALA, n.			Waimanalo, ne	25	0.68
Niulii	200	11.48	Maunawili, ne	300	4.91
Kohala (Mission)	521	10.84	Ahuimanu, ne	350	12.96
Kohala (Sugar Co.)	235	11.36	Kahuku, *n*	25	1.11
Waimea,	2,720	4.45	Ewa Plantation, s	60	0.24
Puuhue	1,847	4.48	Waipahu, s	200	0.00
KONA, w.			Moanalua, sw	15	0.45
Holualoa	1,350	4.40	KAUAI.		
Kealakekua	1,580	5.33	Lihue (Grove Farm), e	200	2.03
Napoopoo	25	4.43	Lihue (Molokoa), e	300	1.71
KAU, se.			Lihue (Kukaua), e	1,000	5.27
Honuapo	15	0.53	Kealia, e	15	1.00
Naalehu	650	0.71	Kilauea, ne	325	5.75
Hilea	310	0.50	Hanalei, n	10	14.92
Pahala	850	1.66	Haena	15	14.05
Moaula	1,700	1.05	Eleele, s	200	0.12
PUNA, e.			*Wahiawa Mountain, s*	*2,100*	12.26
Volcano House	4,000	4.22	McBryde (Residence)	850	1.95
Olaa, Mountain View	1,690	15.81	Lawai	450	3.21
MAUI.			East Lawai	10	2.81
Waiopae Ranch, s	700	0.00	West Lawai	200	1.86
Kaupo (Mokulau), s	285	2.88			
Haiku	700	8.14			
Kula (Waiakoa)	2,700	1.93	*Delayed April reports.*		
Puuomalei	1,400	10.33	Kailua	......	1.20
Haleakala Ranch	2.000	3.29	Moaula	......	1.50
Wailuku	200	1.84	Wahiawa Mount, c	......	18.25
OAHU.			Eleele	......	0.95
Punahou (W. B.), sw	47	1.34	Kula	......	0.54

NOTE.—The letters n, s, e, w, and c show the exposure of the station relative to the winds.

Approximate percentages of district rainfall as compared with normal: Hilo, 180; Hamakua, 400; Kohala, 280; Waimea, 160; Kona, 85; South Kau, 45; North Kau, 120; Puna, 110; Maui, varying from 100 to 200; Oahu, 50, except Ahuimanu, 200; South Kauai, 66; North Kauai, 150.

Mean temperatures: Pepeekeo, Hilo district, 100 feet elevation, average maximum, 76.0°; average minimum, 68.5°; Waimea, 2,730 elevation, 73.4°, and 62.4°; Kohala, 521 elevation, 75.4° and 65.9°; Waiakoa, Kula, Maui, 2,700 elevation, 81.7° and 58.5°; United States Magnetic Observatory, 50 elevation, 85.5° and 65.7°; Ewa Mill, 50 elevation, 81.4° and 66.7°.

Mr. Fleming, at the Magnetic Observatory, reports 9 a. m. dew-point, 62.5°; relative humidity, 57.5; 9 p. m., 62.3° and 73.5; Ewa, mean dew-point, 64.4°; humidity, 70.5; Kohala, 65.6° dew-point; 80 humidity.

Heavy surf 3d, 18th, and 30th. Earthquakes reported, none. Snow fell on Mauna Kea 3d and 4th. Thunder and lightning, Oahu, 12th. Marked haze 10th. "After-glow" (with solar haze), probably from the smoke of the Martinique eruption, reported from Hawaii 21st; first seen on Oahu 22d, and continued thereafter, red for first two or three evenings, then more gray-green and yellow-green effects. Solar haze by day tinged with violet ray, afterwards white.

OBSERVATIONS AT HONOLULU.

The station is at 21° 18′ N., 157° 50′ W.

Hawaiian standard time is 10h 30m slow of Greenwich time. Honolulu local mean time is 10h 31m slow of Greenwich.

Pressure is corrected for temperature and reduced to sea level, and the gravity correction, —0.06, has been applied.

The average direction and force of the wind and the average cloudiness for the whole day are given unless they have varied more than usual, in which case the extremes are given. The scale of wind force is 0 to 12, or Beaufort scale. Two directions of wind, or values of wind force, or amounts of cloudiness, connected by a dash, indicate change from one to the other.

The rainfall for twenty-four hours is measured at 9 a. m. local, or 7.31 p. m., Greenwich time, on the respective dates.

The rain gage, 8 inches in diameter, is 1 foot above ground. Thermometer, 9 feet above ground. Ground is 43 feet, and the barometer 50 feet above sea level.

Meteorological Observations at Honolulu, May, 1902.

Date.	Pressure at sea level.	Temperature.		During twenty-four hours preceding 1 p. m. Greenwich time, or 1:30 a. m. Honolulu time.									Total rainfall at 9 a. m., local time.
				Temperature.		Means.		Wind.		Average cloudiness.	Sea-level pressures.		
		Dry bulb.	Wet bulb.	Maximum.	Minimum.	Dew-point.	Relative humidity.	Prevailing direction.	Force.		Maximum.	Minimum.	
	*	†	†			‡	‡		§				
1	29.99	70	65.5	79	68	61.3	67	ne.	2–4	5	30.01	29.95	0.00
2	30.00	69	67	78	68	62.5	70	ne.	3–5	5	30.04	29.98	0.20
3	29.95	70	65	74	68	66.3	86	ne.	2–3	10–6	30.04	29.95	0.15
4	29.94	67	61.5	75	68	62.0	73	ne.	3–5	10	30.00	29.94	0.00
5	29.94	64	61	76	67	56.0	62	nne.	4	2	29.99	29.90	0.00
6	29.89	62	59.7	76	60	58.7	70	ne.	3–4	7	29.98	29.87	0.00
7	29.94	68	63.7	76	59.5	58.7	70	nne.	1–3	8–5	29.96	29.88	0.00
8	29.95	63	61	77	64	61.3	72	ne.	3–0	10	29.99	29.91	0.00
9	29.96	70	63.5	78	62	59.0	66	nne.	3	1	30.01	29.89	0.01
10	30.00	70	63.5	78	66	62.5	70	ne.	3–5	2–8	30.05	29.95	0.00
11	30.06	70	65	76	69	60.5	69	nne.	5–3	3	30.10	29.99	0.00
12	30.05	72	67	78	69	61.3	69	ne.	3	3	30.11	30.03	0.00
13	30.04	70	69.3	79	71	66.3	77	ne.	3	8	30.10	30.03	0.33
14	30.07	72	69	80	69	67.7	81	ene.	3–1	6	30.12	30.04	0.07
15	30.10	72	65	80	71	64.7	72	ne.	3–5	4	30.14	30.06	0.00
16	30.09	72	65.5	79	70	61.3	66	ne.	4	3–6	30.13	30.03	0.02
17	30.07	72	68	79	68	61.3	66	ne.	4	5	30.14	30.07	0.01
18	30.05	68	67.3	81	72	66.5	75	ne.	3	5	30.10	30.01	0.04
19	30.02	66	64.7	82	67	65.7	74	nne.	3–0	3	30.09	29.99	0.00
20	29.98	73	67.5	82	65	65.5	77	ne.	2–0	1	30.04	29.96	0.01
21	30.01	74	69	82	72	65.3	71	ne.	3–1	3	30.06	29.96	0.01
22	30.05	74	68	82	72	66.7	73	ne.	3	5	30.08	29.99	0.00
23	30.06	74	67.5	81	72	66.0	72	ne.	4	5	30.09	30.01	0.04
24	30.06	74	68	81	71	65.3	70	ne.	4	6	30.10	30.02	0.03
25	30.05	73	67	81	72	64.0	68	ne.	3–2	7	30.14	30.06	0.04
26	30.08	72	66.5	78	71	63.7	71	ne.	3–1	8	30.10	30.02	0.12
27	30.09	73	67	80	68	63.3	70	ne.	4–2	6	30.12	30.03	0.01
28	30.08	71	63.5	80	71	63.3	69	ne.	4–5	4	30.14	30.08	0.02
29	30.04	72	65.5	79	69	61.3	66	ne.	3–4	3	30.11	30.02	0.18
30	30.04	73	66	81	69	62.7	67	ne.	4	3–1	30.08	29.98	0.04
31	30.02	72	65.5	80	71	62.7	67	ne.	4	3	30.08	30.01	0.01
Sums	......	......	......	......	......	......	......	......	......	......	......	......	......
Means	30.022	70.4	65.6	79.0	68.4	63.0	70.7	......	3.2	4.7	30.072	29.987	1.34
Departure	+.004	......	......	......	......	—1.0	+0.4	......	......	+0.3	......	......	—1.34

Mean temperature for May, 1902, (6 + 2 + 9) ÷ 3 = 73.4; normal is 74.2. Mean pressure for May, 1902, (9 + 3) ÷ 2 = 30.0[illegible]3; normal is 30.029.

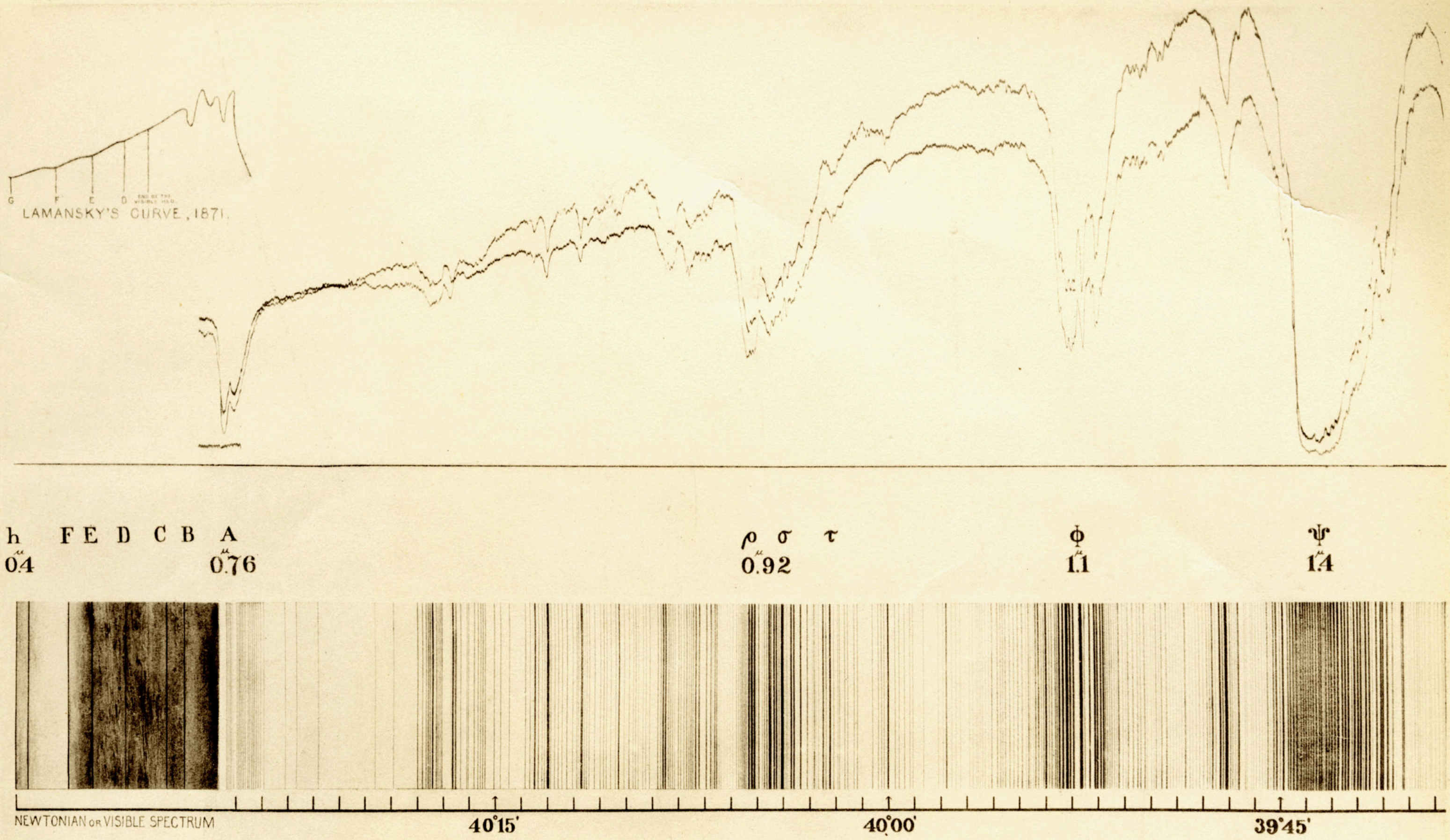
* This pressure is as recorded at 1 p. m., Greenwich time. † These temperatures are observed at 6 a. m., local, or 4.31 p. m., Greenwich time. ‡ These values are the means of (6 + 9 + 2 + 9) ÷ 4. § Beaufort scale.

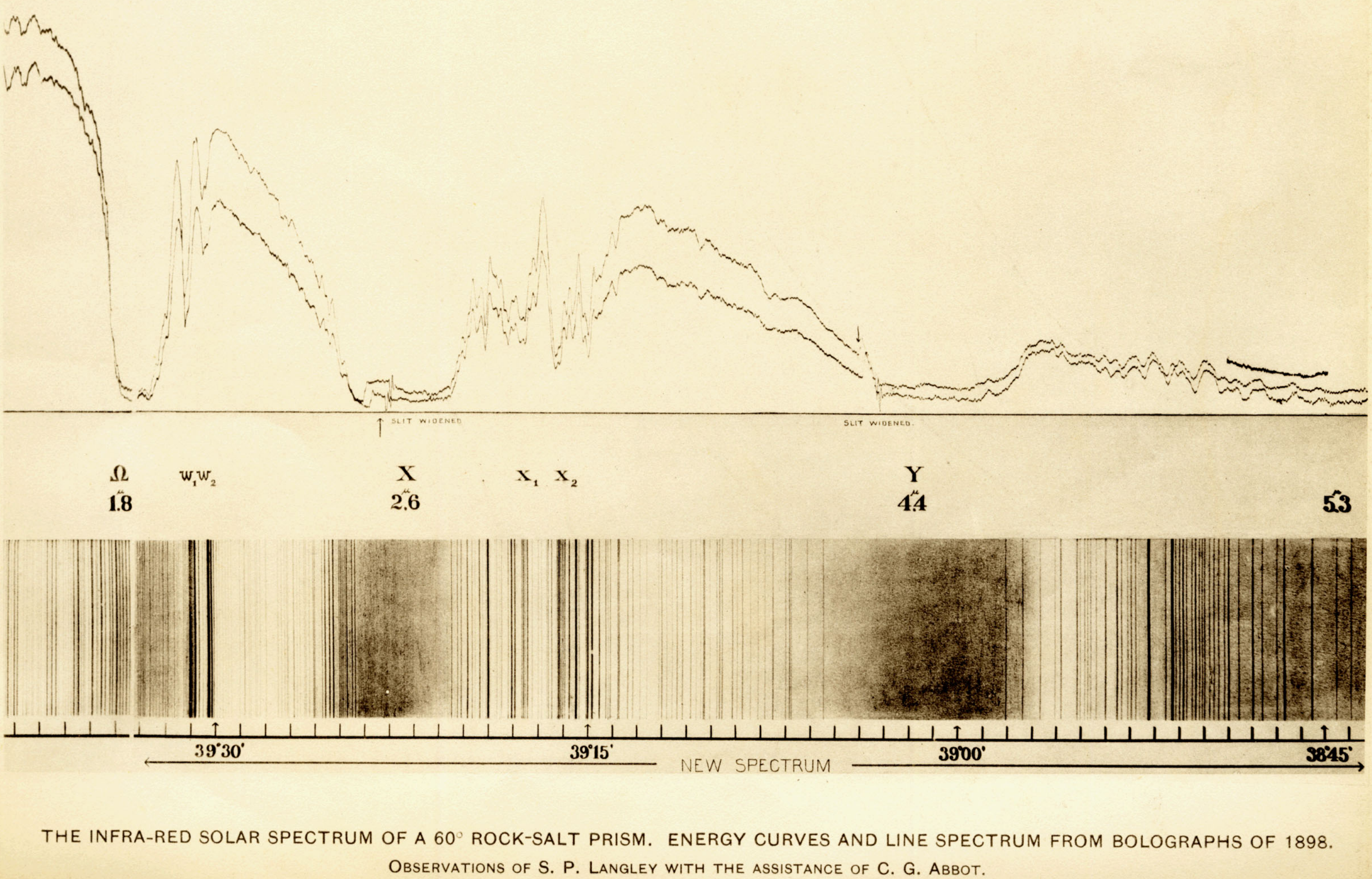
CLIMATOLOGY OF COSTA RICA.

Communicated by H. PITTIER, Director, Physical Geographic Institute.

[For tables see page 292.]

Notes on the weather.—In San Jose the pressure was slightly below the normal, the daily means being very low on the 11th (662.87), 23d (662.54), 24th (662.36), 25th (662.86), and 31st (662.57). The highest means occurred on the 1st (664.39) and 16th (664.17). The temperature was slightly above normal and very uniform throughout the month, the relative humidity rather low, and the sunshine normal. On the Atlantic slope the rainfall was generally excessive and was almost uninterrupted at a few stations. At Port Limon the heat and dampness were at a maximum and numerous cases of yellow fever were reported from the Santa Clara district. On the Pacific slope the precipitation during the rainy season just ended has been in marked excess over that of previous years.





THE INFRA-RED SOLAR SPECTRUM OF A 60° ROCK-SALT PRISM. ENERGY CURVES AND LINE SPECTRUM FROM BOLOGRAPHS OF 1898.

OBSERVATIONS OF S. P. LANGLEY WITH THE ASSISTANCE OF C. G. ABBOT.